# A PREDICTIVE MODEL OF “FAVORABLE” VERSUS “UNFAVORABLE” GROWTH TYPE FOR ORTHODNTIC TREATMENT PLANNING

A Thesis

by

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ABSTRACT

**Purpose**

The purpose of this study was to use longitudinal cephalometric data to identify cephalometric characteristics associated with "favorable" and "unfavorable" craniofacial growth patterns in adolescents.

**Materials and Methods**

This retrospective longitudinal study included 226 untreated adolescent subjects, ages 10-15. Subjects were grouped as "favorable" and "unfavorable" based on the horizontal relationships of the maxillary and mandibular skeletal bases, defined by ANS and Pg. They were grouped based on these relations at 10 and 15, as well as on the changes that occurred between 10 and 15. Statistical analyses, including paired t-tests, bivariate correlations, and multiple regressions, were used to determine the associations. Discriminant analysis was used to predict group membership at age 15.

**Results**

Horizontal maxillomandibular relationships of females, but not males, worsened between 10 and 15 years of age. The majority (58%) of the subjects with favorable horizontal relationships at 10 maintained their favorable horizontal relationships. Relationships at 15 were most closely associated with changes or relationships between T1 and T2. Multiple regression showed that the Y-axis, ANS-N-Pg and symphysial angle explained approximately 60% of the variation in horizontal relationships at age 15. Discriminant function, using these three variables, correctly predicted "favorable" or "unfavorable" relations at age 15 77.4% of the time.

**Conclusions**

While most horizontal relationships are stable, individual variability is great. To determine an individual's relationship at 15, information about their relationships at 10 and the changes between 10 and 15 are needed, with the changes beting the most important. Horizontal relations at age 15 are able to be predicted using the variables of Y-axis, ANS-N-Pg, and symphysial angle. Using these variables it is possible to predict if a subject will have favorable or unfavorable relations with over 75% accuracy.

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# 1. INTRODUCTION AND LITERATURE REVIEW

## 1.1 Introduction

According to a 2017 JCO survey of orthodontists, 77% of case starts are adolescents. [1] In these patients, growth is actively modifying the dentofacial complex while the clinician is attempting to correct the orthodontic problems. The phrase “the patient has a lot of growth left” is often used when developing orthodontic treatment plans, but this is complicated by individual variation in growth patterns. Depending on a patient’s facial growth pattern, growth can either be useful or detrimental in solving orthodontic problems. Determining the role that growth will play is a vital part of an orthodontic diagnosis for two reasons. First, goals that are achievable and realistic depend in great part on what you can reasonably expect from growth. As stated in a 2017 article establishing guidelines for the assessment of patient growth, orthodontists can “work smarter” by incorporating growth into their treatment plans. [2] Secondly, the importance of growth does not end post-treatment. It must also be considered in order to distinguish between the changes caused by treatment and those that were due to growth.

Early efforts at growth prediction were based on pattern extension, which assumed that individuals more or less followed average growth changes. Authors such as Brodie and Broadbent believed that the growth patterns of face were established at an early age, and continued unchanged until growth was completed. [3, 4] This led to the development of growth templates, which predicted a patient’s growth based on the addition of age and sex specific growth increments, with the same increments added to each individual. [5, 6] Later studies recognized that individuals followed growth patterns that differed from average. Multi-level models were used to develop individualized curves to predict growth in subjects with high levels of success. [7, 8] However, these models were complicated and often required multiple cephalograms to make the predictions.

For clinical applications, orthodontists need to know how the horizontal distance between the maxilla and the mandible might be expected to change during treatment. More specifically, they need to know whether favorable or unfavorable growth is to be expected. Favorable and unfavorable growth has been defined based on the horizontal distance between ANS and Pg. [9] Unlike A-point and B-point, ANS and Pg are not influenced by tooth movements, and are easily identified on cephalograms. Unlike angular measures such as the ANB angle, the distance between ANS and Pg is not influenced by the positions of other landmarks. Moreover, there is an association between favorable changes in the horizontal distance between ANS and Pg, and favorable vertical growth changes in subjects. The majority of subjects exhibit horizontal and vertical growth changes that were either both favorable (34%) or both unfavorable (36%). [9]

Various morphological characteristics have been associated with favorable and unfavorable growth patterns. In 1969, Björk, et al utilized metallic implants and superimposed structures to identify characteristics of the mandible associated with true mandibular growth rotation. [10] These features included inclination of the condyle, inclination of the symphysis and lower anterior face height. Ricketts also identified several characteristics and described their relation to growth patterns. [11] Chief among these was the subject's Y-axis which was used by Ricketts to estimate the direction of chin growth during adolescence. To date, the ability of these characteristics to predict favorable and unfavorable growth patterns has not been tested.

The purpose of this study is to establish correlations between subjects' presenting cephalometric characteristics, at approximately 10 years of age, and subsequent expression of a "favorable" or "unfavorable" growth patterns. The ultimate goal is to develop a discriminant analysis to predict the type of growth that a patient is likely to express. This would provide the clinician vital information necessary to make decisions before treatment is initiated.

## 1.2 Problem and Significance

Orthodontists recognize that growth plays an important role in the treatment of adolescent orthodontic patients. Various treatment methods are used in orthodontics in an attempt to direct or modify patient growth. In order to accurately incorporate patient growth into orthodontic treatment planning, a reliable prediction of future patient growth is required. All patient growth is not necessarily beneficial to the orthodontist. In order to fully describe how growth will affect orthodontic treatment, a clinician must predict both the amount and direction of growth. Prior predictive methods have attempted to exactly quantify the direction and amount of future growth. These predictive models of facial growth patterns have largely lacked precision.

Alternatively, patient growth could be classified in dichotomous terms, as either "favorable" or "unfavorable" for achieving the orthodontic goals. Such predictions should have higher predictive precision than attempts at exact prediction. Growth of the human facial skeleton is a complex process dependent on a large number of variables. There has been a great degree of recent focus on complex systems across different disciplines. Attempts to gain tangible knowledge from these complex processes often requires broadening the level of description or the information becomes unmanageable. The same can be applied to facial growth. The multiple variables involved in the process become more manageable when the level of description rises to "favorable" or "unfavorable". [12]

In many complex systems it is the final pattern that matters, not the identity of the individual components that make up the system. [13] A high probability of favorable patient growth provides orthodontists additional information which could influence their treatment plans. With a high probability of favorable future patient growth, a non-extraction treatment could be attempted with increased confidence, or an orthopedic appliance could be considered. Treatment decisions made without accurate predictions of patient growth often require the need for mid-treatment re-evaluation, likely leading to a decrease in treatment efficiency, and an increase in overall treatment time.

### *Specific Objectives/Aims*

The primary question this study hopes to answer is:

1. Can favorable and unfavorable growth types be predicted by a single cephalogram at age 10?

The specific questions this project intends to answer are:

1. Does a favorable or unfavorable growth pattern at age 10 remain stable through adolescent growth to the age of 15?

### *Hypotheses*

Null Hypothesis:

1. Characteristics of an age 10 cephalogram are not predictive of an individual's growth pattern at age 15.

## 1.3 Literature Review

### *Why is Growth Important?*

According to a 2015 JCO survey of U.S. orthodontists, 77% of case starts were adolescents. [1] In these patients, growth is actively modifying the dentofacial complex while the clinician is attempting to correct the orthodontic problems. The orthodontist often attempts to utilize the patient's growth in the correction of orthodontic problems. This is complicated by individual variation in growth between different orthodontic patients. Depending on a patient's facial growth pattern, growth can either be useful or detrimental in solving orthodontic problems. Due to this, an attempt to describe facial growth is a vital part of an orthodontic diagnosis.

In addition, an essential part of the orthodontic diagnosis and treatment planning is the establishment of treatment goals. In order to determine what goals may be achievable and realistic depends a great deal on the patient's growth pattern and how the patient's growth will affect treatment. In many ways orthodontists can "work smarter" by incorporating growth into their treatment plans. [2]

### *Radiographic Evaluation of Growth*

In 1931, Broadbent described the roentgenographic craniostat for standardizing patient positioning during acquisition of radiographs of the craniofacial region. He emphasized that radiographs could be a tool for measuring changes in jaw relation due to growth. Utilizing his Broadbent Head Holder at Western Reserve University, Broadbent began the Bolton study. After 18 months of acquiring serial radiographs at 6-month intervals on 1700 children between the ages of 9 months and 20 years for five year periods, Broadbent observed that certain areas of the cranial base showed no change between certain ages. These areas offer a stable base for relating tracings at different ages and measuring changes in the teeth, jaw and face, beginning the practice of superimpositions in orthodontics. [14] Through his early evaluations of craniofacial radiographs and superimpositions of treated subjects, he determined that while orthodontic treatment often improved the occlusion, abnormal skeletal relationships present at the beginning of treatment often showed no improvement or worsened during treatment. [3]

The Bolton study continued and with more information at his disposal Broadbent expanded on his original observations and proposed a pattern for subject growth. From monthly, quarterly, semiannual and annual radiographs taken over a 12-year period on 5,000 children in the Cleveland area, Broadbent observed that subjects followed a growth pattern that is established early on in life. This pattern, according to Broadbent, was established at the completion of eruption of the deciduous dentition, and once established there is no change in facial proportion. Growth therefore consists essentially of a proportionate increase in size, and predicting future growth is simply an exercise in adding increments to an individual's already established growth pattern. [15]

After Broadbent, others also described human facial growth as occurring along a fixed pattern which is evident at an early age and does not change. In 1940, Brodie outlined the growth pattern of the human head, based on records from both the Bolton Foundation and the Brush Foundation at the University of Illinois. Examining serial records from 3 months to 8 years of age he too determined that the growth pattern of the human face is established at a very early age and does not change. [4] Along with Thompson, Brodie argued that the pattern of a subject's facial growth is evident by 3 months of age or possibly even earlier and does not change after that point. [16] They extended this to mandibular growth, noting that the mandible assumed it's orientation with the rest of the face before any teeth had erupted. This position they described as a “constant and characteristic for the individual” and that growth of anatomic points will travel along straight lines. If the pattern of patient growth is set from an early age, then predicting patient growth is simply a matter of determining how much a patient will add throughout years of growth along their established pattern.

### *Pattern Extension*

Early attempts at predicting growth under the rule that patients follow growth patterns established early in life centered on adding average yearly increments along the pattern of growth. In 1955, Robert Ricketts outlined a cephalometric approach to growth prediction. The objective was prediction of growth of the chin in both direction and amount. Ricketts described cephalometric characteristics that identify a patient’s growth pattern. In order to estimate future growth, population averages for growth changes are added to a patient’s growth pattern. [11]

For characterizing a patient’s growth pattern Rickett’s identified several cephalometric characteristics and described their relation to growth patterns. The first of these is the y-axis, measured by the angle where a line from sella to gnathion crosses the line from basion to nasion. This is used in estimating the direction of chin growth across different patients. Across the 1000 consecutive patients examined by Rickett’s, it was found that on average prognathic patients had a low Y-axis value that would decrease slightly during growth. Retrognathic patients displayed high Y-axis values that showed further opening of approximately 1 degree during growth. [17]

Ten additional characteristics were outlined by Rickett’s that he associated with certain developmental trends of the lower face. The first of these was the angle of the mandibular plane, when higher than average, Rickett’s associated with a tendency for increased vertical chin growth, and when lower than average, a tendency for increased horizontal chin growth. The gonial angle, when obtuse, indicated a tendency for vertical chin growth, and when acute, a tendency for horizontal chin growth. The widths of the mandibular ramus, condyle, and symphysis were all positively related with horizontal growth potential, and narrowness with vertical growth potential. A forward condylar inclination was associated with horizontal growth of the chin and a backward inclination vertical growth of the chin. A long corpus length or low coronoid height indicated horizontal growth potential, while the opposite indicated vertical growth potential. A parallel occlusal plane was associated with horizontal growth of the chin, and a divergent occlusal plane with vertical growth of the chin. Prominent ante-gonial notching showed a tendency for vertical chin growth, and an absence of ante-gonial notching for horizontal chin growth. [17]

Rickett's used the Y-axis value along with an evaluation of the characteristics previously outlined to predict the direction of chin movement during growth. For predicting the amount of growth, a yearly average of 2.5 to 3mm was added to the Y-axis. Though Rickett's acknowledged that there could be differences from the average amount of growth across individuals, there was no individualization of growth amount in Rickett's predictions. [17]

In 1975, Johnston characterized the growth prediction methods of the time to be "mean-change expansions." [5] He presented a simplified visual approach to growth prediction in the form of "forecast grids". These grids could be oriented on a growing patient's lateral ceph for a visual representation of predicted growth changes. When compared to published examples of other predictive schemes of the time, the predictions of Johnston's grid compared closely, but these were still predictive methods based on average growth changes with no attempt at individualization between patients, and assumed that an individual's facial growth direction, once established early in life, did not change.

*Mandibular Rotation*

The hypothesis that facial growth direction, once established, at early age, was maintained throughout life has since been challenged. Björk et. al examined lateral cephalograms of 243 Swedish boys at age 12 and again at age 20 to examine their growth during adolescence. [18] The assumption at the time of Björk's research was that a given relationship between the maxilla and mandible would not change during treatment. [19, 20] It was thought that a patient with a horizontal discrepancy early in growth would retain that discrepancy in their adult form, and conversely a patient with no horizontal discrepancy in adolescence, would not develop one during adolescent growth. [20] Serial cephalometrics were routinely used to identify these variations in growth patterns between different individuals.

Contrary to earlier findings, Björk, et al found large amounts of individual variation in patient growth. These growth changes in individuals followed a normal distribution, showing on average small amounts of change, but with individuals varying towards the extremes, even in the absence of pathology. They found that in individuals "harmonic" sagittal jaw relations could develop disharmonic relations, and vice versa. This variation in individual growth patterns extended to vertical growth.

Could these growth changes in patients be predicted by pre-pubertal characteristics? Björk noted that while morphologic problems become obvious when treatment is delayed until the end of growth, it is no longer possible to utilize growth therapeutically. If individual growth trends can be established earlier, treatment can be designed that incorporates patient growth. [10]

*Characteristics of True Mandibular Rotation*

In 1969 Björk, et al [18] utilized metallic implants and superimposed structures to identify patient characteristics associated with true mandibular growth rotation. The metallic implants placed in their study served as a fixed reference point from which to evaluate craniofacial growth. The authors understood the difficulty of growth prediction, noting that the younger the subject, the more difficult it is to predict final facial form from a single cephalometric analysis. Using lateral head films on 243 Swedish boys at 12 and 20 years of age, the authors found few relationships between dimensions of the face at 12 years of age and the mandibular length at 20 years of age. While mandibular prognathism, on average, increased with age, there were large amounts of individual variation that were unpredictable. The authors also found little correlation between inclination of the mandible at 12 years of age, and the amount of true mandibular rotation during adolescence.

The authors were able use the fixed implants to describe structural features of the jaw that develop in particular types of mandibular rotation. Seven characteristics were identified which, if present in increasing number, indicated a higher predictive potential of true mandibular rotation. These features included the inclination of the condylar head, curvature of the mandibular canal, shape of the lower border of the mandible, inclination of the symphysis, interincisal angle, intermolar angles and anterior lower face height. The authors did qualify that these features are not as clearly developed prior to puberty. [10]

In 1984 Skieller et al tested the predictive value of the features outlined by Björk et al [21]. Their goal was to predict the amount and direction of mandibular growth rotation from a single lateral radiograph at puberty. Evaluating a sample of twenty-one subjects with longitudinal growth data over a six year observation period, 44 morphologic variables were analyzed with multivariate statistics to determine the variables that were predictive of mandibular growth rotation. They found that four variables, in combination, were able to explain 86% of the variation in true mandibular rotation. The first of these variables was mandibular inclination described by the ratio of posterior to anterior face height, gonial angle, and inclination of the lower border of the mandible. The remaining three variables were intermolar angle, shape of the lower border, and inclination of the symphysis. Importantly the subjects in this study consisted mainly of extreme forward or backward mandibular rotators. The authors conceded that cases of moderate rotation could be difficult to predict based on these features. [21]

At this point had clinicians developed an ability to identify the growth pattern of a patient? Baumrind et al [22] examined the reliability with which experienced clinicians could predict mandibular plane rotation. Pre-treatment and post-treatment lateral head films of 64 patients, evenly divided between forward and backward-rotating class II subjects were utilized and the pre-treatment head films were analyzed by five clinicians each with a minimum of 23 years clinical experience. The clinicians were asked to use any method they deemed appropriate to predict, using only the pre-treatment lateral cephalogram, if the patient would display forward or backward rotation. Baumrind defined mandibular rotation by change in the mandibular plane angle relative to Frankfort Horizontal, with an increase indicating backward rotation and a decrease indicating forward rotation. The clinicians were unable to predict mandibular plane rotation with any greater accuracy than would be expected by chance. The same group of researchers also examined thirteen different variables to determine their predictive potential of mandibular plane changes. These included measures such as angle of convexity, AB plane angle, Down's mandibular plane angle, Y-axis, and GoGn:SN among others. They found that none of the thirteen variables displayed statistically significant predictive value of mandibular rotation. [22] All of the predictive methods up to this point had one assumption in common, that the best method available for quantifying growth was through addition of mean averages. No work yet had attempted to adjust that to incorporate individual differences in growth.

# 2. MATERIALS AND METHODS

This retrospective longitudinal study included 226 untreated subjects (106 males, 116 females) who participated in a study conducted by the Human Growth and Research Center, University of Montreal. All of the data pertain to French-Canadian children, drawn from three school districts representing the socioeconomic backgrounds of the Montreal area at large. [23] The children were chosen from 107 randomly selected schools within the three districts. Lateral cephalograms of each child were acquired annually within +/- 2 weeks their birthdays. Children were judged to be French-Canadian based on having at least three of four French-Canadian grandparents. Only children with normal occlusion or untreated Class I and Class II dental malocclusions were included for this study. No Class III subjects were included.

Subjects for this study were selected based on available and suitable lateral cephalograms at T1 (10.4 +/- 1 years of age) and T2 (15.3 +/- .6 years of age). All cephalograms were traced and digitized by the same technician. Twelve landmarks were identified on each tracing. (Table 1, Fig. 1) Rectangular coordinates (X, Y) were used to describe the horizontal and vertical positions of the landmarks, registering on sella and orienting on sella-nasion. All measurements were corrected for radiographic enlargement. Reliability of the horizontal and vertical landmark locations ranged between 95 and 98%. [9]

To describe subjects' horizontal anteroposterior (AP) relationships, the maxillary skeletal base was defined by ANS and the mandibular skeletal base was defined by Pg. These points were used for three reasons (1) they are commonly used to describe maxillary and mandibular position, (2) they are relatively independent of changes in tooth position unlike A and B point, and (3) they are easily located on a lateral cephalogram. [9] To measure changes in landmark position between T1 and T2, each subject's serial cephalograms were superimposed on stable natural structures in the anterior cranial base and cranium. [24] Reliability for cranial base superimposition was greater than 98%. [25] Horizontal difference between ANS and Pg were evaluated by transferring both structures to the natural reference line (RL), constructed from T1 S-N minus 7 degrees. (Figure 2) Subjects at T1 and T2 were defined as having either a favorable or unfavorable AP relations if their horizontal differences at each time point were less than or greater than average, respectively. Subjects were also grouped as having favorable or unfavorable growth changes, based on whether the horizontal differences between ANS and Pg decreased or increased, respectively.

Ten predictor variables were calculated. (Table 1; Fig. 3, 4) They were derived from previous studies pertaining to adolescent growth and chosen because of their connection with facial growth patterns. [10, 21, 26] Certain variables related to the relationship of the mandible to the cranial base. They indicated both horizontal and vertical facial patterns. Others defined characteristics of the mandible itself, such as shape of the symphysis.

All continuous data was found to be normally distributed. Independent t-tests were used to determine between-group differences. Bivariate correlations estimated the associations between the predictor variables and horizontal relationships. Multiple stepwise regression was used to predict both the T2 horizontal relationships and changes in horizontal relationship that occurred between T1 and T2. In addition to the 10 predictor variables, sex and $ANSPg_{T1}$ were included in the regressions to control for possible size effects. Prior to the multiple regression, 20% of the sample was randomly chosen and reserved to validate the multiple regression equations. Based on the variables identified by the multiple regression, discriminant function was performed to predict group membership of subjects classified as having favorable and unfavorable growth type.  For validation of the estimates, a one-out validation procedure was performed.

# 3. RESULTS

## 3.1 Sex Differences

There were no statistically significant differences in horizontal relationship at T1($ANSPg_{T1}$) between males and females. (Table 2) There was a statistically significant increase in the horizontal distance between ANS and Pg in females, corresponding to a worsening of their horizontal relationships ($\Delta$ANSPg). This resulted in significantly worse horizontal relationships in females at T2 compared to males ($ANSPg_{T2}$).

Among the ten predictor variables, significant differences were present between males and females, with differences becoming more pronounced between T1 to T2. The mandibular plane angle, Y-axis, ANS-N-Pg, condylar inclination, gonial angle, palatal plane angle, and cranial base angle all showed significant T1 differences between males and females. At T2, all of these variables in addition to the symphysial angle showed significant sex differences.

## 3.2 Pattern Changes

The majority (58%) of subjects with favorable horizontal relationships at T1 maintained their favorable horizontal relationships at T2. (Figure 5) There were 42% of favorable T1 subjects, who developed an unfavorable T2 horizontal relationship. Similar patterns were seen among subjects with unfavorable T1 relationship. The majority remained unfavorable at T2, but 41% developed a favorable T2 horizontal relationship.

The majority of subjects with favorable T1 horizontal relationships, worsened between T1 and T2. (Figure 6) There were 45% with favorable T1 relations who improved.

Approximately two-thirds of unfavorable T1 subjects had relations that worsened between T1 and T2, while just over one-third improved.

The greatest group stability was evident between subjects who showed favorable or unfavorable T1 to T2 changes. (Figure 7) Over three-fourths of subjects whose relations improved had favorable T2 horizontal relationships, and just over two-thirds of subjects that worsened between T1 and T2 had unfavorable T2 horizontal relationships.

## 3.3 Predictor Variables

Only one of the ten T1 predictor variables showed a statistically significant difference between subjects who had favorable and unfavorable changes in their horizontal relationship. (Figure 8) Symphysial angle was significantly higher in unfavorable individuals, indicating a flatter chin. All ten of the T1 predictor variables showed significant differences between those subjects who had favorable or unfavorable T2 horizontal relationships. (Figure 9) Those with unfavorable T2 relations were initially more hyperdivergent, had greater AP skeletal discrepancy, larger gonial angles, more backwards inclined condyles, and flat, thin chin buttons.

Most of the predictor variables show moderately low, but statistically significant correlations with horizontal relationship between ANS and Pg at T1, (Table 5) including mandibular plane angle, Y-axis, PAFH, ANS-N-Pg, condylar inclination, gonial angle, symphysial ration, and symphysial angle. Gonial angulation, MPA, Y-axis, and condylar inclination showed the highest correlations with T1 horizontal relationship. The correlation between the T1 predictor variables and horizontal relationship increased over time, with significant moderate to moderately low correlations observed with T2 horizontal relationship. Only 3 of the 10 T1 predictor variables were correlated with changes in horizontal relationships that occurred between T1 and T2, including mandibular plane angle, posterior anterior face height, and symphysial angle. The correlations were all low.

### 3.4 Multiple Regression

Stepwise multiple regression identified no combination of variables that were significantly related to changes of AP relationship that occurred over time (ΔANSPg). Multiple regression did identify the Y-axis as having the highest correlation (R=.640) with horizontal relationships at T2 ($ANSPg_{T2}$), explaining 41% of variation. (Table 6) The next variable to enter the prediction was ANS-N-Pg, which explained an additional 16% of the variation (R=.756). The third variable to enter was the symphysial angle, which explained an additional 3% of variation in the horizontal difference between ANS and Pg at T2. The final equation, explaining 60% of the variation, was

$$\text{ANS-Pg}_{T2} = -1.678 + .056*\text{Y-axis}_{T1} + .069*\text{ANS-N-Pg}_{T1} + .010*\text{SymAng}_{T1}$$

It indicated that $\text{ANS-Pg}_{T2}$ was larger in subjects whose T1 Y-axis, ANS-N-Pg, and SymAng were larger.

Excluding the three variables identified by the first regression, the second stepwise multiple regression identified MPA as the variable explaining the greatest amount of the variability in $ANSPg_{T2}$ (R=.580). The next variable was the symphysial ratio (R=.619), followed by the cranial base angle (R=.650). The final equation, was

$$\text{ANS-Pg}_{T2} = -3.282 + .051*\text{MPA}_{T1} - 1.954*\text{HVSym}_{T1} + .029\text{NSBa}_{T1}$$

explaining 43.3% of the variaition in $ANSPg_{T2}$ (Table 6).

When the equation from the first stepwise multiple regression was applied to the validation sample, a similar association between the predicted and actual $ANSPg_{T2}$ (R=.779). When the second multiple regression was applied to a validation sample similar results were again obtained (R=.640).

### 3.5 Discriminant Function

Discriminant function was not able to identify T1 predictor variables that could distinguish between those whose AP relations increased over time and those whose relations decreased. However, discriminant function was able to predict those individuals who exhibited "favorable" and "unfavorable" relationships at T2. (Table 7) The predictor variables identified in the first stepwise multiple regression yielded a moderately significant discriminant function (Wilks' Lambda=.681; p=<.001). The predictor variable $\text{Y-axis}_{T1}$ was identified as contributing the most to the classification, followed by $\text{ANS-N-Pg}_{T1}$ and $SymAng_{T1}$. Overall, 77.4% of subjects were correctly identified as having either "favorable" or "unfavorable" T2 horizontal relationships. The one out cross validation method showed that 77.4% of subjects were correctly identified.

The three predictor variables identified by the second stepwise multiple regression were also able to discriminate between favorable and unfavorable T2 horizontal relationships (Wilks' Lambda=.814; p=<.001). The predictor variable $MPA_{T1}$ contributed the most to the classification, followed by $NSBa_{T1}$ and $HVSym_{T1}$. Overall, 72.6% of subjects were correctly identified as having either "favorable" or "unfavorable" T2 horizontal relationship. The one out cross validation method identified 71.1% of subjects correctly.

# 4. DISCUSSION

Horizontal skeletal relationships of females worsen during adolescence while male relationships do not. The present study showed that male horizontal relationships did not significantly change between the ages of 10 and 15, while female relations worsened significantly. This produced a statistically significant difference in horizontal relationship between males and females at 15 years of age. No other studies have examined sex differences in anteroposterior skeletal base relationship changes during adolescence. It has been shown that males had a greater decrease in ANB during adolescence, resulting in a smaller ANB angle than girls at 17 years of age. [7] The difference between the sexes in skeletal base relations could be due to differences in mandibular growth. Chavatal et al showed that anterior movements of menton level off in females after approximately 12.5 years of age while inferior movements continue. [7] In contrast, the horizontal movements of males continued up to the age of 15. Nanda et al also showed continued horizontal movement of pogonion in boys after the age of 13, but not in girls. [27] This demonstrates that, when compared to males, adolescent growth in females is more vertical in nature, leading to a worsening of horizontal skeletal base relationships over this time period.

The majority of 10 year olds maintain their horizontal relationships through 15 years of age. Nearly 60% of subjects classified initially as having favorable or unfavorable patterns maintained their horizontal relationships between 10 to 15 years of age. No other studies have examined changes of skeletal base relations of individuals. Most have evaluated average changes. Based on averages, horizontal relations do not change much over time. [27, 28] This is why it was originally thought that individuals maintain their specific growth pattern throughout adolescence. [3, 4] For example, Lux et al, who compared average ANB measurements of subjects with good occlusions, Class I malocclusions, and Class II malocclusions, found higher average ANB angles in Class II malocclusions at age 7, which remained higher through age 15. [29] Ngan et al reported similar results, showing that average values of ANB and N-A-Pg were 3 degrees higher for Class II than Class I subjects, and the difference was maintained from age 7 to age 14. [28] The stability of the individual patterns identified in the present study could partially explain why on average, ANB angles, as well as the maxillomandibular differential exhibit relatively small changes between 10 and 15 years of age.

Importantly, the stability of averages does not mean that growth patterns are not changing on the individual level. Approximately 40% of the subjects in the present study did not maintain their growth patterns. Moreover, whether individuals improved or worsened their relationships between 10 and 15 years was largely unrelated to their 10 year old horizontal relationships. Based on 186 untreated subjects, Roberts found that the standard deviation of the ANB angle increased 0.41 degrees between the ages of 10 and 15, indicating an increase in variability over this time period. [8] More importantly, the standard deviation of the individual changes in ANB that occurred was almost three times higher. This indicates that while average values for ANB diverged only slightly, inter-subject variability was much greater. As such, average values mask individual variability in growth patterns. Even though averages do not change much, individual relations may be improving or worsening over time.

Horizontal growth changes between 10 and 15 years of age are most closely related to the horizontal relationship an individual will have at 15 years of age. Of all the comparisons made, those with favorable or unfavorable relations at 15 years of age were most likely to have favorable or unfavorable growth changes during adolescence. While Ngan et al found no statistically significant differences in SNB and S-N-Pg between Class I and Class II individuals prior to age 11, there were differences thereafter. Individuals with Class I relationships at age 15 showed increases in both their SNB and S-N-Pg angles, while Class II individuals did not. [28] In other words, difference in mandibular growth during adolescence determined the sagittal relationship at age 15. The data presented in the present study, along with previous literature, indicates that growth changes during adolescence contribute more to the final horizontal relationships at age 15 than the horizontal relationship that individuals present with at age 10. Since the changes that occur between 10 and 15 are largely unrelated to their status at 10 years of age, this indicates that the horizontal changes that occur during adolescence are largely influenced by factors different than those that influenced growth prior to adolescence.

One of the major changes that occur during adolescence is the increased rates of muscle growth. Estimates of muscle mass show that increases are much greater during adolescence than childhood, and that sex differences are established during adolescence. [30, 31] Malina et al found that amounts of excreted creatinine over 24 hours almost doubled in individuals between the ages of 10 and 18, indicating large increases in muscle tissue. [32] Based on previously established associations between muscle strength (i.e. bite force) and craniofacial growth [33], it is reasonable to assume that the large increases in muscle mass during this time period could be causing changes in the growth patterns of individuals.

Another factor shown to influence adolescent maxillomandibular growth patterns is airway obstruction. The effects of reduced respiratory function on facial growth have been well documented. [34] For example, Lindor-Aronson showed that subjects exhibiting difficulties in nasal breathing showed increases in lower face height and anterior-posterior discrepancies between the upper and lower jaws. Based on Scammon's curves of systemic growth, lymphoid tissue reaches 200% of it's adult size at age 12 and does not return to normal adult size until age

20. [35] The large increase in lymphoid tissue during this time might be contributing to airway obstructions, which could affect facial growth patterns during adolescence. An increase in prevalence of asthma in adolescents has also been demonstrated. Couriel et al reported that the prevalence and level of morbidity attributed to asthma is higher in adolescence than in younger children. [36] In combination or separately, adolescent differences in muscle strength and airway capacity could explain changes in facial growth patterns during this time.

Perhaps most importantly, it is possible to predict horizontal relationship at age 15 based on cephalometric variables at age 10. The present study showed that at 10 years of age, three measures combined explained 60% of the variation present in the horizontal relationships at age 15. While previous studies have not evaluated the ability to predict horizontal maxillomandibular relationships, it has been shown that 86% of the variation in mandibular rotation can be explained based on gonial angle, intermolar angle, shape of the lower border, and the inclination of the symphysis. [21] However the prediction of rotation included extreme forwards and backwards rotators, which the authors indicated could have inflated the correlation. The amount of variation explained in the present study is slightly less (10-15%) than those reported in growth predictions using multi-level modeling. [7, 8] It is possible that multi-level modeling provides more accurate estimates of facial growth than multiple regression because it allows for individualized growth curves, which regression does not. Correlations produced in the present study were similar to those reported by Judy et al (56-67%), and substantially greater than Kolodziej et al, who was only able to explain 25% of the variation in mandibular growth. [37, 38] Their low correlation may have been due to the fact that prediction was based only on one measure of ante-gonial notching. Importantly, these predictions are all significantly better than those reported by Ricketts, Popovich and others using pattern extension. [5, 6, 11] Pattern extension, which is based on the assumption that all individuals will more or less follow average growth changes, cannot accurately predict changes individual to individual because of the large amount of individual variability.

Based on only three predictor variables it is possible to correctly classify individuals as having a favorable or unfavorable growth pattern. In the present study, the subject's Y-axis, ANS-N-Pg, and symphysial angle made it possible to predict whether their final facial relationship would be favorable or unfavorable 76% of the time. These three variables explain three different and relatively independent aspects of the subjects' facial pattern, that combine to increase prediction accuracy. The Y-axis describes the vertical orientation of the mandible relative to the cranium, ANS-N-Pg describes the sagittal relationship between the maxilla and mandible, and symphysial angle describes the contour of the chin. All of this information, in combination, is needed to predict favorable or unfavorable growth. When discriminant function used MPA, NSBa, and symphysial ratio, it correctly predicted the final facial relationships 73% of the time. These measures provide information about the same three facial characteristics, supporting the notion that these separate pieces of information each contribute to predictive accuracy. The accuracy achieved in the current study is greater than previously reported for binary craniofacial predictions. Auconi et al attempted to predict favorable or unfavorable horizontal relationships of Class III subjects at age 15 from their cephalometric characteristics at age 10. Their discriminant analysis correctly classified 60% of individuals, but it required seven predictor variables. [39] Their sample size was much smaller (n=91) than in the present study and was limited to Class III subjects, which could partially explain the differences observed.

The predictive models developed in the current study were all shown to have high external validity. For discriminant function, the one-out validation procedure resulted in a similar level of accuracy indicating the model can be applied to other samples. Furthermore, the multiple regression equations, when applied to a 20% validation sample produced correlations of similar strength. It is important that any predictive model be validated in order to confirm that it can be applied to other samples. While Auconi et al reported that their discriminant analysis correctly classified 60% of individuals, they did not validate their results on individuals not included in their original sample. [39] It is possible that the high number of predictor variables they used to develop their discriminant analysis would make it difficult to validate their results. In contrast, all of the predictive models developed in the current study were based on only three predictor variables, possibly leading to greater stability of the models.

Clinically, an accurate prediction of favorable or unfavorable growth in 3 out of 4 patients is useful. Treatment goals and approaches should change based on the growth changes that a patient is likely to undergo during treatment. While the predictions in the current study are not 100%, they are better than the average clinician would be able to achieve during a routine initial exam. Furthermore, the variables identified in the current study provide a guide that clinicians use when evaluating growth potential. An evaluation of the subject's vertical inclination, the sagittal relationship between the maxilla and mandible, and the characteristics of the bony chin should be evaluated in combination when forecasting an individual's growth pattern. Finally, the distinct differences seen in the present study between horizontal relationships at age 10, and the pattern of growth over the next 5 years indicate that orthodontists must base decisions about future growth on characteristics that patient's present with, together with the knowledge that unexpected changes should be expected for a large number of subjects during adolescence. There are environmental factors, not solely genetics, contribute to growth of the face and particularly the mandible. Orthodontic treatment is taking place during a time when many factors are combining to influence growth patterns. Orthodontists can be one of these environmental factors contributing to patient growth patterns in favorable or unfavorable ways depending on the treatment decisions that are made.

# 5. CONCLUSIONS

1. Females horizontal skeletal relationships worsen during adolescence while males don't. Females tended to have more hyperdivergent characteristics especially at 15 years of age
2. While the majority of 10-year old's maintain their horizontal relationships through 15 years of age, the changes that occur over time are a better indicator of 15 year old horizontal relationship.
3. Changes in horizontal relationship between 10 and 15 years of age are moderately correlated with individuals' horizontal relationship at 15 years of age.
4. Subjects characteristics at 10 years of age are not related to the changes in horizontal relationship that occur between the ages of 10 and 15, but they are related to 15 year-old relationships.
5. Y-axis, ANS-N-Pg and symphysial angle at 10 years of age explain 60% of the variation of the horizontal relationship at age 15.
6. Those same variables are able to correctly classify individuals as having favorable or unfavorable horizontal relationships 76% of the time.

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APPENDIX A

FIGURES

Figure 1. Landmarks evaluated on subject cephalograms.

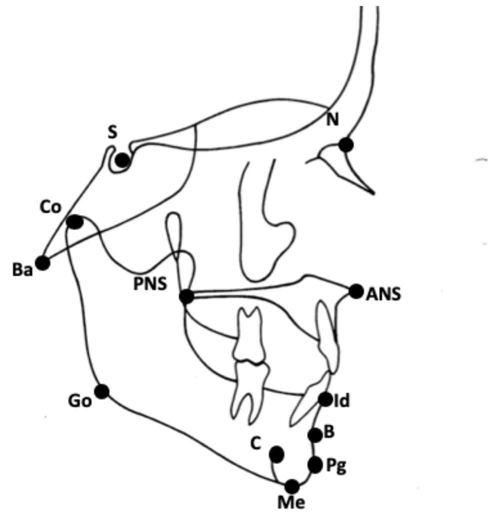



Figure 2. Horizontal relationship between ANS and Pg transferred to the natural structure reference line.

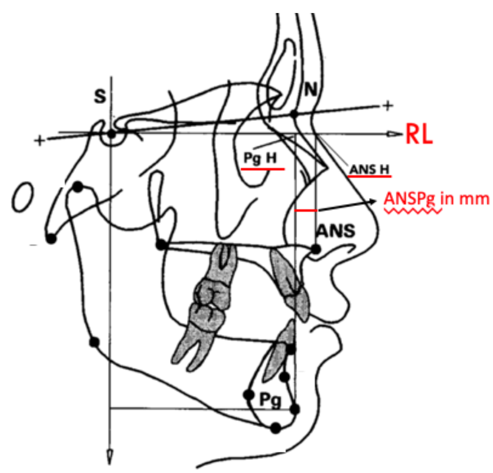


Figure 3. Condylar inclination predictor variable. (CondInc)

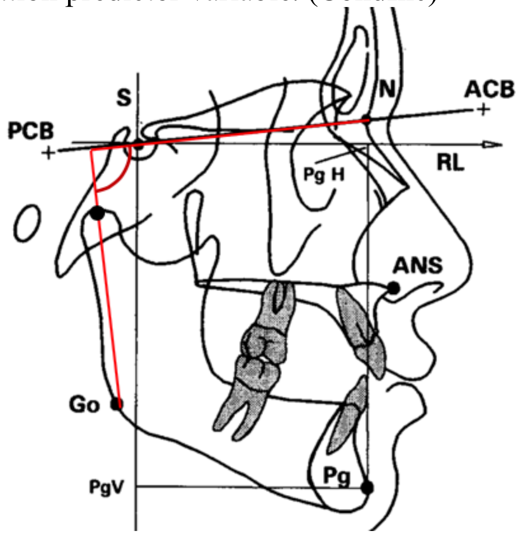



Figure 4. Predictor variables of symphysial ratio and angle. (HVSym and SymAng)

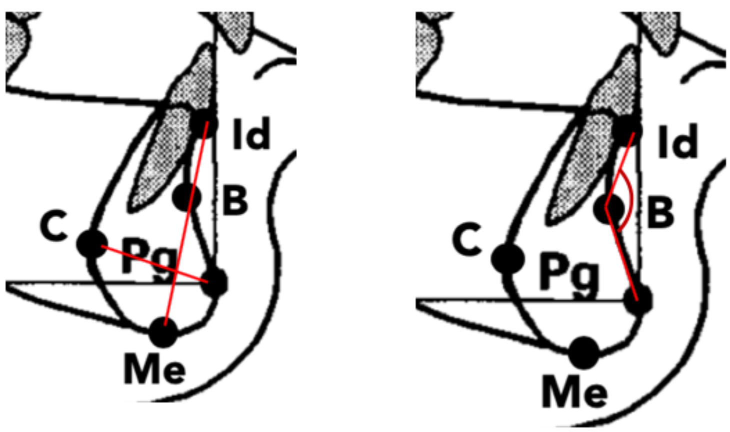


Figure 5. Pattern changes between favorable and unfavorable growth types at T1 and T2.

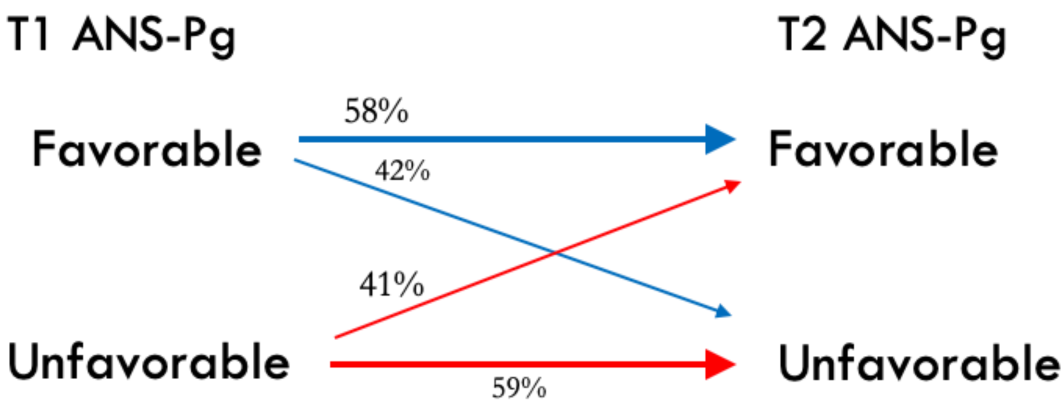



Figure 6. Pattern changes between T1 growth type and growth changes between T1 and T2.

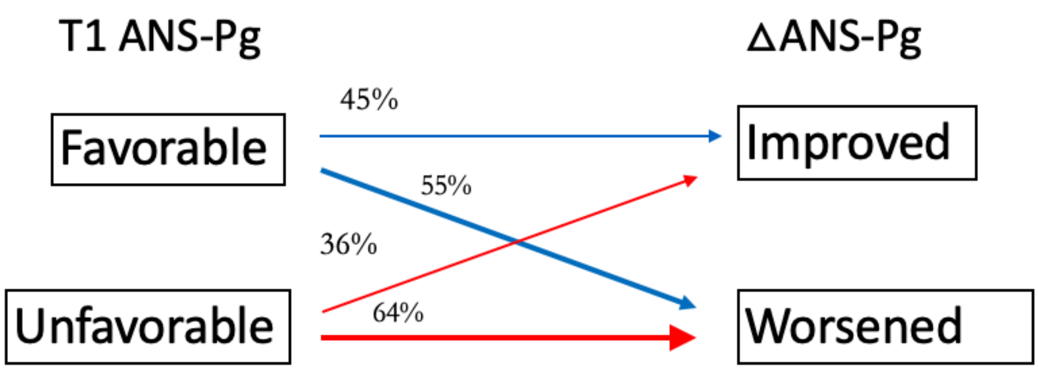



Figure 7. Pattern between growth changes and T2 growth types.

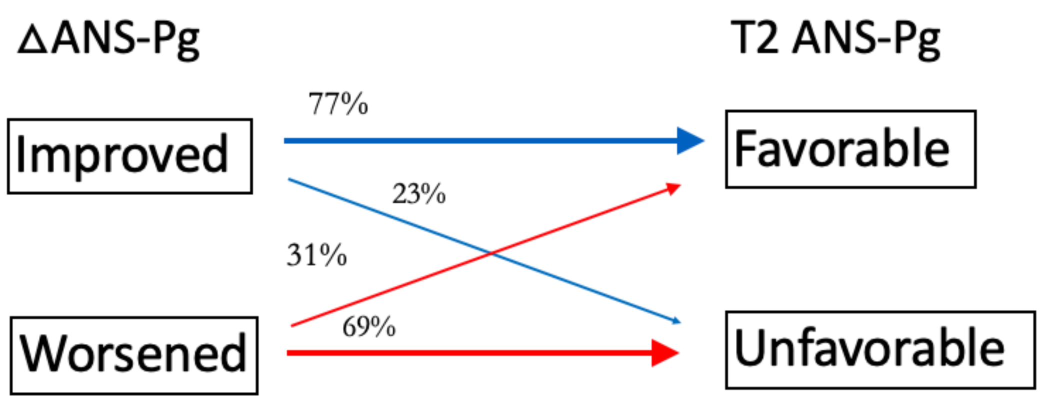


Figure 8. Differences in T1 predictor variables between subjects who displayed favorable and unfavorable changes in their horizontal relationship.

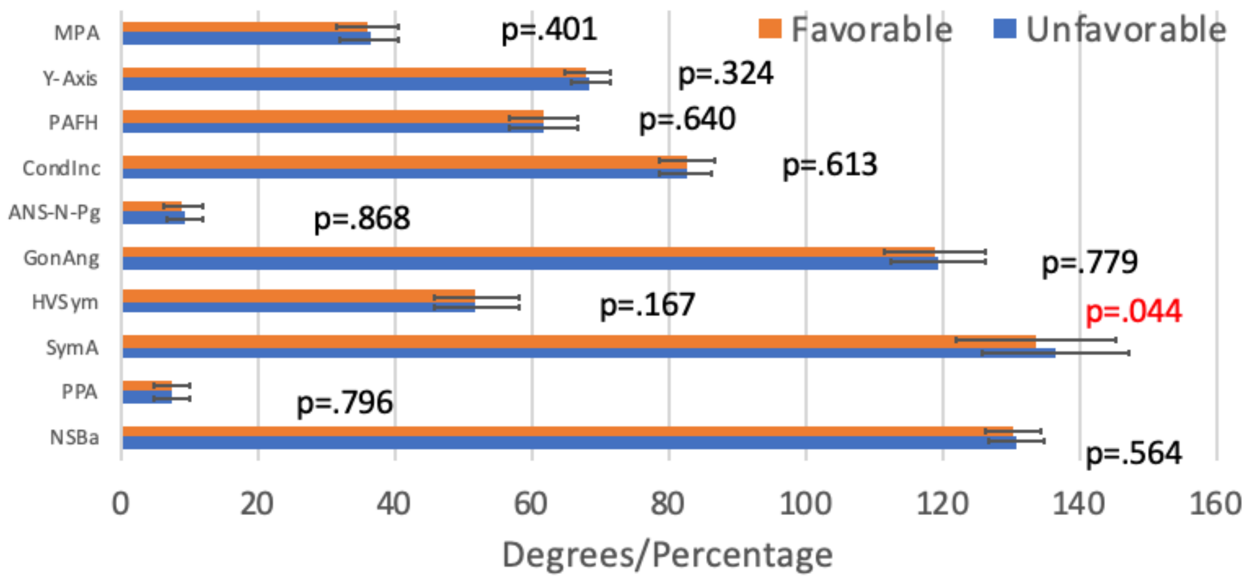
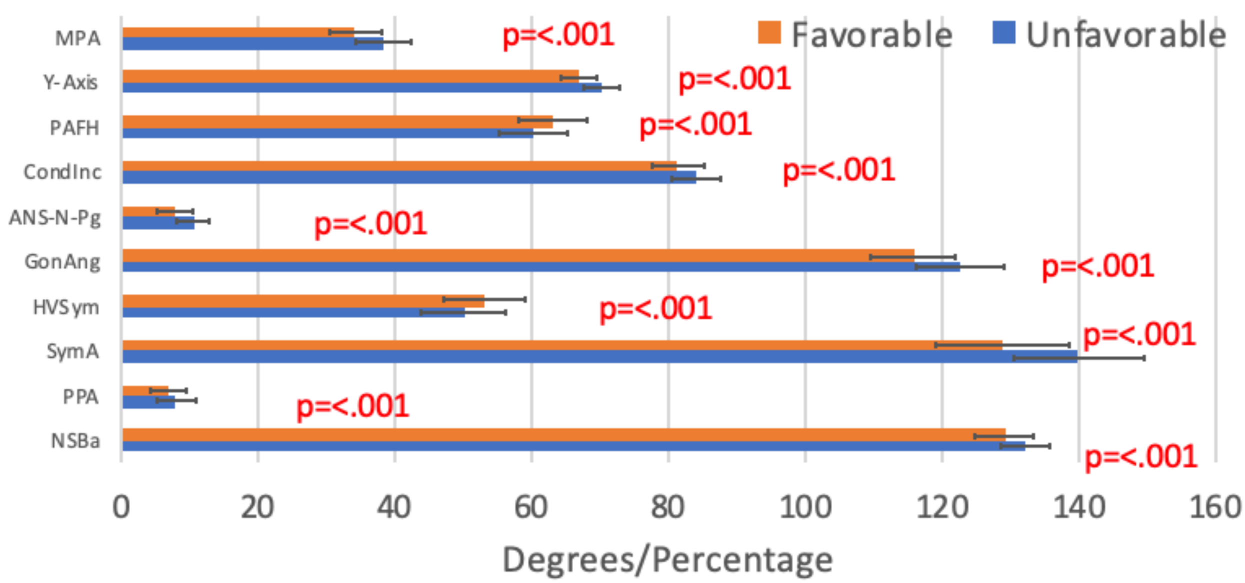



Figure 9. Differenes in T1 predictor variables between subjects who had favorable and unfavorable horizontal relationships at T2.



APPENDIX B

TABLES

Table 1. Landmark and measurement definitions and abbreviations.

| Name | Definition | Abbreviation |
|---|---|---|
| **Landmarks** | | |
| Anterior Nasal Spine | Most anterior point of the maxilla | ANS |
| B Point | Point of deepest curvature between infradentale and pogonion as defined | B |
| Basion | Midpoint of the anterior margin of the foramen magnum | Ba |
| C Point | Point of deepest curvature of the lingual portion of the mandibular symphysis | C |
| Condylion | Most superior point of the mandibular condyle | Co |
| Gonion | Midpoint of the angle of the mandible, defined by bisection of the angle formed by the tangents to the posterior border of the ramus and the inferior border of the mandible | Go |
| Infradentale | The intersection point of the anterior lower incisor and the crestal bone | Id |
| Menton | The most inferior point of the mandibular symphisis | Me |
| Nasion | Junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose | N |
| Pogonion | Most anterior point of the bony chin | Pg |
| Sella | Center of the sella turcica of the sphenoid bone by inspection | S |
| **Measurements** | | |
| Mandibular plane angle | Angle formed by the intersection of line Go-Me with line S-N | MPA |
| Y-axis | Angle formed by the intersection of line S-Gn and S-N | Y-Axis |
| Posterior to anterior face height | Ratio of the distance from S to Go divided by the distance from N to Me | PAFH |
| ANS-N-Pg | Angle formed between the points ANS, S, and Pg | ANS-N-Pg |
| Condylar Inclination | Angle formed between the line Go-S and S-N (See Fig. 3) | CondInc |
| Gonial Angle | Angle formed between Ar, Go, and Me | GonAng |
| Symphysial Ratio | Ratio of the distance from C to Pg divided by the distance from Id to Me (See Fig. 4) | HVSym |
| Symphysial Angle | Angle formed between Id, B, and Pg (See Fig. 4) | SymA |
| Palatal Plane Angle | Angle formed between the line ANS-PNS and S-N | PPA |
| Cranial Base Angle | Angle formed between N, S, and Ba | NSBa |

Table 2. Horizontal relationship between ANS and Pg in mm.

| | Male | | Female | | |
|---|---|---|---|---|---|
| | **Mean** | **SD** | **Mean** | **SD** | **Prob** |
| $ANSPg_{T1}$ | 12.9 | 4.05 | 13.5 | 3.81 | .232 |
| $ANSPg_{T2}$ | 12.7 | 5.03 | 14.7 | 5.05 | .004 |
| ΔANSPg | 0.10 | 2.88 | -1.10 | 2.88 | .002 |

Table 3. Differences in T1 predictor variables between subjects who had favorable or unfavorable changes of their horizontal relationship (ΔANSPg).

| | | Unfavorable Change | | Favorable Change | | |
|---|---|---|---|---|---|---|
| | **Units** | **Mean** | **SD** | **Mean** | **SD** | **Prob** |
| MPA | Deg | 36.5 | 4.3 | 36.0 | 4.5 | .401 |
| Y-axis | Deg | 68.6 | 3.0 | 68.2 | 3.2 | .324 |
| PAFH | % | 62.0 | 5.0 | 62.0 | 5.0 | .640 |
| ANS-N-Pg | Deg | 9.2 | 2.7 | 9.1 | 3.0 | .868 |
| CondInc | Deg | 82.6 | 3.8 | 82.9 | 4.0 | .613 |
| GonAng | Deg | 119.4 | 6.9 | 119.2 | 7.4 | .779 |
| HVSym | % | 52.0 | 6.0 | 52 | 6.0 | .167 |
| SymA | Deg | 136.6 | 11.7 | 133.6 | 10.7 | .044 |
| PPA | Deg | 7.4 | 2.7 | 7.3 | 2.7 | .796 |
| NSBa | Deg | 130.9 | 4.1 | 130.5 | 4.2 | .564 |

Table 4. Differences in T1 predictor variables of subjects who exhibited favorable or unfavorable relationships at T2 ($ANSPg_{T2}$).

| | | Unfavorable T2 Outcome | | Favorable T2 Outcome | | |
|---|---|---|---|---|---|---|
| | **Units** | **Mean** | **SD** | **Mean** | **SD** | **Prob** |
| MPA | Deg | 38.2 | 4.0 | 34.2 | 3.8 | <.001 |
| Y-axis | Deg | 70.1 | 2.7 | 66.8 | 2.6 | <.001 |
| PAFH | % | 60.0 | 5.0 | 63.0 | 5.0 | <.001 |
| ANS-N-Pg | Deg | 10.5 | 2.3 | 7.8 | 2.7 | <.001 |
| CondInc | Deg | 84.0 | 3.7 | 81.4 | 3.7 | <.001 |
| GonAng | Deg | 122.6 | 6.5 | 115.9 | 6.2 | <.001 |
| HVSym | % | 50.0 | 6.0 | 53.0 | 6.0 | <.001 |
| SymA | Deg | 140.0 | 9.7 | 129.0 | 9.7 | <.001 |
| PPA | Deg | 7.9 | 2.8 | 6.8 | 2.7 | .003 |
| NSBa | Deg | 132.1 | 3.7 | 129.3 | 4.3 | <.001 |

Table 5. Pearson correlation between the 10 predictor variables and T1 horizontal relationship, T2 horizontal relationship, and change in horizontal relationship.

| | $ANSPg_{T1}$ | | $ANSPg_{T2}$ | | ΔANSPg | |
|---|---|---|---|---|---|---|
| **T1 Variables** | **Correlation** | **Sig. (2-tailed)** | **Correlation** | **Sig. (2-tailed)** | **Correlation** | **Sig. (2-tailed)** |
| **Mandibular Relation** | | | | | | |
| MPA | .314 | <.001 | **.604** | <.001 | -.182 | **.007** |
| Y-axis | .302 | <.001 | **.668** | <.001 | -.122 | .070 |
| PAFH | -.195 | .006 | -.353 | <.001 | .169 | **.012** |
| ANS-N-Pg | .237 | .001 | .614 | <.001 | -.061 | .364 |
| **Mandibular Characteristics** | | | | | | |
| CondInc | .292 | <.001 | .372 | <.001 | -.008 | .908 |
| GonAng | .355 | <.001 | **.579** | <.001 | -.115 | .087 |
| HVSym | -.159 | .025 | -.360 | <.001 | .119 | .076 |
| SymA | -.238 | .001 | -.615 | <.001 | .185 | **.006** |
| **Other** | | | | | | |
| PPA | .122 | .086 | .247 | <.001 | -.039 | .568 |
| NSBa | .043 | .546 | .372 | <.001 | -.070 | .298 |

Table 6. Multiple Regression of T1 predictor variables for the dependent variable $ANSPg_{T2}$.

| Step | Constant | Var 1 | Var 2 | Var 3 | R | $R^2$ |
|---|---|---|---|---|---|---|
| **Multiple regression 1** | | | | | | |
| 1 | -5.811 | Yaxis (.105) | N/A | N/A | .640 | .406 |
| 2 | -4.478 | Yaxis (.075) | ANS-N-Pg (.078) | N/A | .756 | .565 |
| 3 | -1.678 | Yaxis (.056) | ANS-N-Pg (.069) | SymA (-.010) | .772 | .596 |
| **Multiple regression 2** | | | | | | |
| 1 | -1.066 | MPA (.068) | N/A | N/A | .580 | .337 |
| 2 | 0.246 | MPA (.058) | HVSym (-1.857) | N/A | .619 | .383 |
| 3 | -3.282 | MPA (.051) | HVSym (-1.954) | NSB (.029) | .658 | .433 |

Table 7. Discriminant function between subjects with favorable and unfavorable T2 relationships ($ANSPg_{T2}$).

| **Discriminant Coefficients** | | | **Wilks' Lambda** | | **Classification** | **Validation** |
|---|---|---|---|---|---|---|
| **Var 1** | **Var 2** | **Var 3** | **Est.** | **Prob** | **% Correct** | **% Correct** |
| YAxis (.497) | ANS-N-Pg (.464) | SymAng (-.365) | .642 | <.001 | 76.3 | 76.3 |
| MPA (.688) | HVSym (-.275) | NSB (.460) | .739 | <.001 | 72.5 | 71.2 |